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(54) Title: METHODS AND SYSTEMS RELATING TO LIGHT SOURCES FOR USE IN INDUSTRIAL PROCESSES

(57) Abstract: System and methods are disclosed in connection with a reaction at or below the surface of a work object, in the context of a fluid flow fostering the reaction. In some example embodiments, the reaction is fostered by (1) creating fluid flow of an inerting fluid over a surface during exposure of the surface to a predetermined type of light, (2) creating fluid flow comprising a reactive species that reacts with another species at or below the work surface in a predetermined manner and/or (3) creating a fluid flow comprising a catalytic species that catalyzes a reaction in a predetermined manner, e.g., during exposure of the surface to a predetermined type of light. In some example embodiments, a light source is employed that comprises a solid-state light source, e.g., a dense array of solid-state light sources. In at least one of such example embodiments, the reaction is a photoreaction associated with the light source.

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METHODS AND SYSTEMS RELATING TO LIGHT SOURCES FOR USE IN INDUSTRIAL PROCESSES

CROSS-REFERENCE TO RELATED APPLICATIONS

The present patent application claims priority to U.S. Provisional Patent Application Serial No. 60/640,925, entitled "Solid State UV curing in inert or oxygen reduced environments," invented by Duwayne R. Anderson et al., and filed on December 30, 2004, and to U.S. Provisional Patent Application Serial No. 60/647,749, entitled "Methods and systems relating to light sources for use in industrial processes," invented by Mark D. Owen et al., and filed on January 26, 2005, each of which is incorporated by reference herein.

BACKGROUND

The inventive subject matter disclosed herein relates to light sources for use in industrial processes, such as for causing material transformation. More particularly, the inventive subject matter disclosed herein relates to systems and methods directed to techniques for providing a fluid flow in association with a work surface that is the subject of a reactive process in the presence of light energy.

Light can be used to initiate various chemical reactions. Such light-initiated processes are a critical part of a number of industrial processes. The applicability of light as part of a particular process depends on several key properties of the light source, including, as examples, total optical power emitted by the source, wavelength(s) emitted by the source, source coherence, radiance of the source (power/area x steradian), degree of collimation, and power stability.

A particular application of light that has significant economic implications in today's industrial application is the polymerization, curing or other reaction as to adhesives and other light sensitive materials. The application of light may contemplate that the materials be irradiated through low transmittance layers. The application of light may contemplate that one or more specific wavelengths be employed. The application of light may contemplate that the light catalyze the reaction. The application of light generally contemplates that the light be absorbed by one or more materials employed in the process (e.g., adhesive). The application of light tends to also contemplate that the

light either not be absorbed by one or more materials employed in the processed and/or, if absorbed undesirably, that any thermal or other undesirable aspects of that absorption be addressed (e.g., mitigation of undesirable heating of a work object). In any case, the application of light in association with the material that is to be bonded, sealed, or chemically altered by a polymerization or other reaction (e.g., with or without catalysis) presents a significant hurdle, and opportunities for advancement, in a number of industrial applications today.

In some chemical reactions, the presence of oxygen is detrimental to the chemical reaction. The detrimental effect of oxygen is well known in the industry. For example, a paper entitled "Nitrogen Inerting Benefits Thin UV Coating Cure," by Dr. L. Misev of Ciba Specialty Chemicals Inc., proposes that:

> The presence of oxygen during the UV cure process can have a detrimental effect on the cure response of free radical systems. Oxygen reacts with the free radical and forms peroxy radicals by reaction with the photoinitiator, monomer or propagating chain radical. The reactivity of the peroxy radicals is insufficient to continue the free radical polymerization process, leading to chain termination and an under cured system.
>
> Thin coatings, typically printing inks and overprint varnishes, are particularly affected because oxygen replenishment is most effective in the few micrometers below the film surface. This counteracts the increased photoinitiator radical formation resulting from highest UV light intensity at the film surface. Therefore, when UV curing takes place in air the degree of double bond conversion does not depend only on the light intensity distribution within a coating according to the Beer-Lambert law.
>
> The degree of benefit from inerting, typically by nitrogen purging of the UV exposed ink or coating surface, depends on various factors and can be best determined under the specific processing conditions.

According to Dr. Misey, a technique for overcoming the problem of oxygen-inhibited cures is by removing the oxygen by smothering the coating surface with an oxygen-free gas, such as nitrogen.

Certain inerting techniques are proposed in other technical literature. For example, a paper entitled "Progress in Organic Coatings, Overcoming oxygen inhibition in UV-curing of acrylate coatings by carbon dioxide inerting: Part II," by K. Studer et al. proposes:

> The most effective way to overcome oxygen inhibition is to work in an inert atmosphere, by flushing the UV oven with nitrogen [6,7] or carbon dioxide [8]. The latter gas being heavier than air, it can be easily maintained in a container.

As described by K. Studer et al., then, a common technique for inerting is to flush a container, apparently to immerse a work object in an inert atmosphere of nitrogen or carbon dioxide.

References to other technical literature appears to indicate that certain nitrogen-inerting techniques are known. See, for example, "DYNAMIC MECHANICAL ANALYSIS OF UV-CURABLE COATINGS WHILE CURING," by R.W. Johnson, DSM Desotech Inc., Elgin, IL 60120; R. Müller, in: Proceedings of the RadTech Europe Conference, 2001, p. 149 (referenced in Studer et al. as [6], as set forth above); and T. Henke, in: Proceedings of the RadTech Europe Conference, 2001, p. 145 (referenced in Studer et al. as [8], as set forth above).

In some circumstances, it is either unsafe or impractical to immerse a work object in an oxygen-depleted, inert atmosphere. For example, when the work object is in an environment that must be shared with people, such inerting would be unsafe to those people. In other situations, immersion inerting might be impractical, for example, when the work object is part of, or moved by, a fast-moving mechanical assembly. In these other situations, the moving machinery will tend to undesirably mix, distribute, or disperse the inerting atmosphere (e.g., mixing the inert atmosphere with oxygen, tending to be work at odds with the depletion function), and/or may require adaptable gaskets and seals for effective isolation (i.e., with attendant ramifications, e.g., expenses, maintenance, etc.).

Such a situation is encountered when curing adhesives used for bonding materials together to form optical storage media. Representative of such media are a compact disk (CD) or digital versatile/video disk (DVD). A CD or a DVD (CD/DVD) is generally formed from two disc-shaped transparent pieces of material. The flat surface of one or both of the discs is typically coated with a reflective surface, which is typically formed from a metal. The coated, flat pieces are conventionally bonded together using a UV-curable adhesive resin.

Figures 2A-2C respectively depict cross-sectional views of three exemplary conventional DVDs 210, 220 and 230. Such conventional DVDs have a cross-section that is similar to a conventional CD. In particular, Figure 2A depicts a cross-sectional view of a portion of a one-sided single-layer disc 210, which is commonly referred to as a DVD-5. A DVD-5 can contain up to 4.38 GBytes of data. As shown in Figure 2A, DVD 210 includes two layers 211 and 212 of polycarbonate (PC) material that are each typically 600 microns thick. Sandwiched between polycarbonate layers 211 and 212 are a UV-curable resin layer 213 that is typically 20-50 microns thick and an aluminum layer 214 that is typically 45-60 nm thick. Figure 2B depicts a cross-sectional view of a portion of a single-sided dual-layer disc 220, which is commonly referred to as a DVD-9. A DVD-9 can contain up to approximately 7.95 GBytes of data. Disc 220 includes two layers 221 and 222 of polycarbonate material that are each typically 600 microns thick. Sandwiched between polycarbonate layers 221 and 222 are an aluminum layer 223 that is typically 50-60 nm thick, a UV-curable resin layer 224 that is typically 40-70 microns thick, and a layer 225 formed from silicon, silver or gold that is typically 10-15 nm thick. Figure 2C depicts a cross-sectional view of a portion of a dual-sided DVD disc 230, which is commonly referred to as a DVD-10. A DVD-10 can hold up to 8.75 GBytes of data with 4.38 GBytes on each side. Disc 230 includes two layers 231 and 232 of polycarbonate material that are each typically 600 microns thick. Sandwiched between polycarbonate layers 231 and 232 are a first aluminum layer 233 that is typically 50 nm thick, a UV-curable resin layer 234 that is typically 40-70 microns thick, and a second aluminum layer 235 that is typically 50 nm thick. These are representative optical storage discs and it is contemplated that these and other constructions vary depending on various factors (the factors including, e.g., the type and production facility). For example, in the constructions above, the reflective layer is sometimes chosen to be silicon.

A central aspect of the construction of optical storage media is that the components thereof are bonded together with adhesives. This aspect is understood to remain even though the materials or other nature of the components may change (e.g., as the industry moves to other standards like Blue Ray and HD-DVD (High Density Digital Versatile/Video Discs)).

In a CD/DVD, the UV-curable adhesive resin directly between the two polycarbonate layers preferably is isolated from oxygen in the surrounding atmosphere and, therefore, the adverse effects caused by the presence oxygen may be eliminated. Even in that case, when the two polycarbonate layers are placed together with the UV-curable resin disposed in between, some of the resin may seep from, flow out of or otherwise be established outside the two polycarbonate layers and, therewith, form a bead on or along one or more circumferential edges of the polycarbonate layers (e.g., on or along the outside edge). The bead of resin on or along the edge may tend to be exposed to oxygen during the curing process. Depending on the particular resin used and the exposure to oxygen, incomplete curing may occur, producing an undesirable, "tacky" edge of the resulting CD/DVD.

The machinery used to manufacture CD/DVDs is complex and includes rapidly moving parts. Accordingly, this machinery is understood to be generally incompatible with immersion inerting, as proposed in the technical literature.

Another problem associated with CD/DVD manufacture is thermal loading of the polycarbonate layers when the adhesive resin layer between the polycarbonate layers is cured. Thermal loading of the polycarbonate layers may lead to deviations, or distortions, of the resulting CD/DVD (e.g., in the axial, lateral and thickness dimensions) that, in turn, generally leads to poor read/write characteristics of the resulting CD/DVD. Thermal loading may also result in undesirable chemical properties of the materials involved (e.g., modification of those properties). Additionally, as the CD/DVD industry migrates towards lower initiator concentrations and shorter wavelengths (higher energy radiation) for reading and writing information on CD/DVDs, two different power densities may be employed during adhesive curing operations: one power density for an aerobic environment (i.e., the oxygen-present environment at the edge of a CD/DVD) and another power density for an anaerobic environment (i.e., the oxygen-reduced or oxygen-lacking environment internal to the CD/DVD).

In other cases of curing, the desired results may be characterized and have parameters other than those desirable to manufacture of CD/DVD. As an example, in curing acrylate inks in digital graphics, the desired finish is to be dry and should have a high gloss. This can be achieved by dissipating a large amount of energy into the polymer ink formulations and/or by inerting methods. The print media tends to be composed of a variety of materials, and some can be addressed by a higher energy method, which methods generally are incompatible with other materials, e.g., plastics like polyvinylchloride, polyethylene, polypropylene, as well as various heat sensitive substrates.

The aforementioned challenges and problems in manufacturing optical storage media and digital graphics are representative of problems and challenges in industrial processing, particularly processing in the presence of light. Accordingly, there is a need for methods and systems that provide improved environmental conditions so as to foster such processing. Without limiting the more general need set forth above, as illustrated via the representative problems identified above, there is a need for inerting selected portions of a work piece or substrate. As an example, such inerting may be at a surface or edge of a work piece or substrate (e.g., a rapidly moving work piece or substrate) having associated therewith, or comprising, light curable materials, which materials may include UV-curable materials, such as inks, coatings, or adhesives, such that, a reaction is properly effected (e.g., the reaction initiates, proceeds and/or is completed without or substantially without detrimental effects, such as those caused by the presence of oxygen or other inhibitor, or other impurity, contaminant or material, if present or present at or above a particular metrics, will be at odds with the reaction).

Additionally, a technique is needed for providing light in the context of the above inerting. Additionally, a technique is needed for providing variable light attributes during a photoreaction for a substrate or work piece that has different, environmental, physical or chemical properties, for example, a work piece or substrate having an aerobic environment and an anaerobic environment.

What is needed is a technique for enabling a reaction at or below a surface of a work piece, in which a fluid flow is provided in association with such surface of the work piece and, in the context of the work piece being exposed to a light, the reaction is fostered at or below the surface of the work piece. In additional, what is needed is a

technique for enabling a reaction, as stated above, wherein the reaction is a photoreaction relating to the light exposure.

SUMMARY

In exemplary embodiments, the inventive subject matter disclosed herein provides systems and methods for a reaction at or below a selected portion of a surface of a work piece such that a fluid flow is created to foster the reaction. In these embodiments, the reaction may be a photoreaction (e.g., a reaction associated with application of light energy). (As used in this application, (a) "fluid flow" means flow of one or more selected fluids, at one or more selected times, over or otherwise in association with at least one selected surface of a work piece or substrate, so as to foster a particular reaction; and (b) "foster" means to promote, enable or otherwise contribute to a reaction so that such reaction is properly effected (e.g., the reaction initiates, proceeds and/or is completed without or substantially without inhibition, interference or other detrimental effects, such as those caused by the presence of oxygen or other inhibitor and/or, as the case may be, other impurity, contaminant or material which, if present or present at or above a particular metric, may be at odds with the reaction).)

In exemplary embodiments, a reaction is fostered by creating fluid flow in association with at least one selected portion of a work object. The fluid flow may be associated with the selected portion by a selected fluid flowing over the selected portion.

In exemplary embodiments, the fluid may comprise an inerting fluid. Examples of such inerting fluid include nitrogen or other inert gas or liquid, alone or in combinations. Examples of such inerting fluid also include gases or liquids selected to react with oxygen or other inhibitor or material(s), so as to produce an inert product (e.g., a product that will not inhibit the reaction or otherwise be at odds with fostering the reaction).

In exemplary embodiments, the fluid may comprise a reactive species. In such embodiments, that fluid reacts (e.g., photoreacts) with another species in a predetermined manner. Such another species typically is a component of, or is used in making, the work object. Such another species may also be an inhibitor, an impurity, a contaminant or other undesirable material.

In exemplary embodiments, the fluid may comprise a catalytic species that catalyzes the reaction (e.g., a photoreaction) in a predetermined manner.

In exemplary embodiments, the fluid may comprise combinations of one or more inerting, reactive, catalytic or other species. Any such combination may be provided at once (e.g., in mixtures or other chemical combinations), in sequences (e.g., separately or in mixtures or other combinations), or both. Any such combination may be provided variously over different portions of the work piece whether at once, in sequence or both.

In exemplary embodiments, the reaction comprises a photoreaction employing a selected light source. The selected light source may be any known light source, for providing light appropriate to the photoreaction. Such light source, generally, addresses various parameters, e.g., particular wavelength(s) and power for a particular photoreaction.

In exemplary embodiments, the light source is a solid state light source. Without limiting the generality of the foregoing, the solid state light source may comprise a dense array of light emitting diodes (LEDs).

In an exemplary embodiment, fluid flow provides a desired inerting agent or reactive species at at least one selected portion of a surface of a work piece to displace, remove or otherwise substantially mitigate or overcome the action of a predetermined agent that inhibits, interferes with, has a detrimental effect on or otherwise is at odds with a photochemical reaction or other predetermined reaction or processing at or in the surface of the work piece or substrate.

In another exemplary embodiment, the fluid combines with another species to form one of an inerting, reacting or catalytic species. In another exemplary embodiment, the fluid flow can be a unidirectional fluid flow. In still another exemplary embodiment, fluid flow can be a multi-direction fluid flow (e.g., flowing in two directions at the same time, typically at two different locations and/or flowing in one direction at one time and in another direction at another time). In yet another exemplary embodiment can a radial fluid flow. In a further exemplary embodiment, the fluid flow can be without or without substantial turbulence (in such case, the fluid flow may be referred to herein as "laminar flow"). Alternatively, the fluid flow can be with a selected degree of turbulence.

In other exemplary embodiments, the fluid its flow direction and nature, and other of its parameters may be selected, so as to provide one or more characteristics. Such

selections typically are in the context of application of the fluid flow. As examples of this contextual selection, such selections typically respond to the reaction, the work product's components, the environment (including inhibitors and other materials), and the light source. Such selections are contemplated to include any one or more of the above-described types of fluids, flow directions, flow natures and other parameters, together or separately from other fluid types, flow directions, flow natures and other parameters.

Advantages of the inventive subject matter disclosed herein are provided by a device and a method for enabling a reaction (e.g., a photoreaction) at or below a surface of a work piece or substrate, in which a fluid flow is provided over or otherwise in association with such surface of the work piece, the work piece being exposed to a light source, so as to foster the reaction at or below the surface of the work piece or substrate. In one exemplary embodiment, the fluid comprises an inerting species, and the reaction is a photoreaction that would be in an aerobic environment, but for the fluid flow. The inerting species could be, for example, nitrogen, carbon dioxide, argon and/or helium. In another exemplary embodiment, the reaction is for a polymerization reaction. In still another exemplary embodiment, the fluid comprises a reactive species. In yet a further exemplary embodiment, the fluid comprises a catalytic species. In one exemplary embodiment, the fluid flow is substantially parallel to a portion of the work piece.

The reaction (e.g., a photoreaction) could be for curing an ink formation on a substrate. Alternatively, the reaction could be for curing a coating on a work piece. As yet another alternative, the reaction could be for setting an ink.

In one exemplary embodiment, the work piece includes first and second layers of material and a third layer of material between the first and second layers, and the reaction (e.g., photoreaction) enables the third layer of material to bond the first and second layers of material together. For example, the work piece could comprise a precursor for optical storage media, such as a CD-type device, a DVD-type device, a Blue Ray DVD-type device or an HD-DVD-type device.

In another exemplary embodiment, the light comprises one or more wavelengths of between about 250 nm and 450 nm. In one instance of such embodiment, the light is generated by a light source comprising a solid-state light source. Alternatively, the light source could comprise a dense array of solid-state light sources.

The inventive subject matter disclosed herein also provides various methods directed to fluid flow. In an example embodiment, a method is provided for applying inert fluid, such as nitrogen, carbon dioxide, or the like, to the edge of a rapidly moving substrate involving UV-cured materials, such as inks, coatings, or adhesives, so that a chemical reaction can be fostered (e.g., without being exposed to, or otherwise mitigating, the detrimental effects caused by the presence of oxygen). In such example method, the inert fluid may provide a layer in association with the edge.

Additionally, the inventive subject matter disclosed herein provides a method for providing different power densities of light in connection with a photoreaction. In such example method, the different power densities of light may be provided at different times or at different locations of a work piece, or combinations of same. In a particular instance of such method, the work piece may have an aerobic environment and an anaerobic environment, and the power densities may be selectively applied as to each such environment.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing is not intended to be an exhaustive list of embodiments and inventive subject matter disclosed herein. The inventive subject matter disclosed herein is illustrated by way of example and not by limitation in the accompanying figures in which like reference numerals indicate similar elements and in which:

Figure 1 depicts an exemplary UV-light curing process;

Figure 2A depicts a cross-sectional view of a portion of a one-sided single-layer disc, which is commonly referred to as a DVD-5;

Figure 2B depicts a cross-sectional view of a portion of a single-sided dual-layer disc, which is commonly referred to as a DVD-9;

Figure 2C depicts a cross-sectional view of a portion of a dual-sided DVD disc, which is commonly referred to as a DVD-10;

Figure 3A depicts a top view of an exemplary embodiment of a fixture for a fluid flow process;

Figure 3B depicts a cross-sectional view of the exemplary embodiment of fixture taken along line A-A in Figure 3A;

Figure 4 depicts an exemplary configuration of a fixture, including a light source;

Figure 5A depicts a top view of an exemplary embodiment of a spindle base shown in Figures 3A and 3B;

Figure 5B depicts a cross-sectional view of an exemplary embodiment of the spindle base shown in Figure 5A taken along line B-B;

Figure 5C depicts a side view of the exemplary embodiment of the spindle base shown in Figure 5A;

Figure 5D depicts a perspective view of the exemplary embodiment of the spindle base shown in Figure 5A;

Figure 6A depicts a top view of an exemplary embodiment of the outer ring member shown in Figures 3A and 3B;

Figure 6B depicts a cross-sectional view of the exemplary embodiment of the outer ring member shown in Figure 6A taken along line C-C;

Figure 6C depicts a perspective view of the exemplary embodiment of the outer ring member shown in Figure 6A;

Figure 7A depicts a top view of an exemplary embodiment of the inner ring member shown in Figures 3A and 3B;

Figure 7B depicts a cross-sectional view of the exemplary embodiment of the inner ring member shown in Figure 7A taken along line D-D;

Figure 7C depicts a side view of the exemplary embodiment of the inner ring member shown in Figure 7A;

Figure 7D depicts a perspective view of the exemplary embodiment of the inner ring member shown in Figure 7A;

Figure 8A depicts a top view of an exemplary embodiment of the platter shown in Figures 3A and 3B;

Figure 8B depicts a side view of the exemplary embodiment of the platter shown in Figure 8A;

Figure 8C depicts a perspective view of the exemplary embodiment of platter the shown in Figure 8A; and

Figure 9 illustrates a basic construction of an exemplary embodiment of a lighting module having a plurality of solid-state light emitters.

DETAILED DESCRIPTION

The inventive concepts disclosed herein overcome the problems and challenges in the prior art by providing methods and systems that are adaptable to varying environmental, physical, and chemical conditions for a reaction, photoreaction or other processing (e.g., photo-processing). Principles of the exemplary embodiments of the inventive subject matter disclosed herein are illustrated in the following discussion.

In one or more exemplary embodiments, the inventive subject matter disclosed herein provides systems and methods in connection with a reaction at or below a selected portion of a surface of a work piece such that a fluid flow is created to foster the reaction. In these embodiments, the reaction may be a photoreaction (e.g., a reaction associated with application of light energy). (As used in this application, (a) "fluid flow" means flow of one or more selected fluids, at one or more selected times, over or otherwise in association with at least one selected surface of a work piece or substrate, so as to foster a particular reaction; and (b) "foster" means to promote, enable or otherwise contribute to a reaction so that such reaction is properly effected (e.g., the reaction initiates, proceeds and/or is completed without or substantially without inhibition, interference or other detrimental effects, such as those caused by the presence of oxygen or other inhibitor and/or, as the case may be, other impurity, contaminant or material which, if present or present at or above a particular metric, may be at odds with the reaction).)

In exemplary embodiments, a reaction is fostered by creating fluid flow in association with at least one selected portion of a work object. The fluid flow may be associated with the selected portion by a selected fluid flowing over the selected portion.

In exemplary embodiments, the fluid may comprise an inerting fluid. Examples of such inerting fluid include nitrogen or other inert gas or liquid, alone or in combinations. Examples of such inerting fluid also include gases or liquids selected to react with oxygen or other inhibitor or material(s), so as to produce an inert product (e.g., a product that will not inhibit the reaction or otherwise be at odds with fostering the reaction).

In exemplary embodiments, the fluid may comprise a reactive species. In such embodiments, that fluid reacts (e.g., photoreacts) with another species in a predetermined manner. Such another species typically is a component of, or is used in making, the work

object. Such another species may also be an inhibitor, an impurity, a contaminant or other undesirable material.

In exemplary embodiments, the fluid may comprise a catalytic species that catalyzes the reaction (e.g., a photoreaction) in a predetermined manner.

In exemplary embodiments, the fluid may comprise combinations of one or more inerting, reactive, catalytic or other species. Any such combination may be provided at once (e.g., in mixtures or other chemical combinations), in sequences (e.g., separately or in mixtures or other combinations), or both. Any such combination may be provided variously over different portions of the work piece whether at once, in sequence or both.

In exemplary embodiments, the reaction comprises a photoreaction employing a selected light source. The selected light source may be any known light source, for providing light appropriate to the photoreaction. Such light source, generally, addresses various parameters, e.g., particular wavelength(s) and power for a particular photoreaction.

In exemplary embodiments, the light source is a solid state light source. Without limiting the generality of the foregoing, the solid state light source may comprise a dense array of light emitting diodes (LEDs). In such case, the dense array may be implemented so as to emit light of a selected wavelength, of selected wavelengths or in a selected band of wavelengths. Moreover, such dense array generally is implemented so as to provide a selected light power density, e.g., at the work piece. In addition, such dense array generally is implemented so as to control undesirable heating (e.g., of the work piece), including, as an example, in emitting light of selected wavelength(s) (e.g., by not emitting, or substantially so, other wavelengths).

In an exemplary embodiment, fluid flow provides a desired inerting agent or reactive species at at least one selected portion of a surface of a work piece to displace, remove or otherwise substantially mitigate or overcome the action of a predetermined agent that inhibits, interferes with, has a detrimental effect on or otherwise is at odds with a photochemical reaction or other predetermined reaction or processing at or in the surface of the work piece or substrate.

In another exemplary embodiment, the fluid combines with another species to form one of an inerting, reacting or catalytic species. In another exemplary embodiment, the fluid flow can be a unidirectional fluid flow. In still another exemplary embodiment,

fluid flow can be a multi-direction fluid flow (e.g., flowing in two directions at the same time, typically at two different locations and/or flowing in one direction at one time and in another direction at another time). In yet another exemplary embodiment can a radial fluid flow. In a further exemplary embodiment, the fluid flow can be without or without substantial turbulence (in such case, the fluid flow may be referred to herein as "laminar flow"). Alternatively, the fluid flow can be with a selected degree of turbulence.

In other exemplary embodiments, the fluid its flow direction and nature, and other of its parameters may be selected, so as to provide one or more characteristics. Such selections typically are in the context of application of the fluid flow. As examples of this contextual selection, such selections typically respond to the reaction, the work product's components, the environment (including inhibitors and other materials), and the light source. Such selections are contemplated to include any one or more of the above-described types of fluids, flow directions, flow natures and other parameters, together or separately from other fluid types, flow directions, flow natures and other parameters.

Advantages of the inventive subject matter disclosed herein are provided by a device and a method for enabling a reaction (e.g., a photoreaction) at or below a surface of a work piece or substrate, in which a fluid flow is provided over or otherwise in association with such surface of the work piece, the work piece being exposed to a light source, so as to foster the reaction at or below the surface of the work piece or substrate. In one exemplary embodiment, the fluid comprises an inerting species, and the reaction is a photoreaction that would be in an aerobic environment, but for the fluid flow. The inerting species could be, for example, nitrogen, carbon dioxide, argon and/or helium. In another exemplary embodiment, the reaction is for a polymerization reaction. In still another exemplary embodiment, the fluid comprises a reactive species. In yet a further exemplary embodiment, the fluid comprises a catalytic species. In one exemplary embodiment, the fluid flow is substantially parallel to a portion of the work piece.

The reaction (e.g., a photoreaction) could be for curing an ink formation on a substrate. Alternatively, the reaction could be for curing a coating on a work piece. As yet another alternative, the reaction could be for setting an ink.

In one exemplary embodiment, the work piece includes first and second layers of material and a third layer of material between the first and second layers, and the reaction (e.g., photoreaction) enables the third layer of material to bond the first and second layers